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A STUDY OF THE BREAK-UP CHARACTERISTICS
OF CHENA RIVER BASIN USING ERTS IMAGERY

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A STUDY OF THE BREAK-UP CHARACTERISTICS OF CHENA RIVER BASIN
USING ERTS IMAGERY

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16. Abstract <p>Snowmelt and rainfall flooding is a major water resource problem in Alaska. At the present time, forecasting of these floods is based on a sparse hydrological and climatological network. Numerous basins with drainage areas of 5,000 km² and less remain completely un-gaged. The lack of data causes uncertainty in the design of transportation schemes such as the TransAlaska oil pipeline. This project studied the utility of using ERTS-1 imagery as a source of additional data for the prediction of snowmelt runoff, the most dynamic hydrologic event in arctic and subarctic basins. Snow distribution as determined from the satellite imagery was compared with values determined from the conventional snow course stations and with the results of a snowmelt energy model. The Chena River Basin was selected because of the availability of ground truth data for comparison. Very good agreement for snow distribution and rates of ablation was found between the ERTS-1 imagery, the snowmelt model, and field measurements. Monitoring snowmelt rates for relatively small basins appears to be practical. The main limitation of the ERTS-1 imagery is the interval of coverage. More frequent overflights providing coverage are needed for the study of transient hydrologic events. ERTS-1 data is most useful when used in conjunction with snowmelt prediction models and existing snow course data. These results should prove very useful in preliminary assessment of hydrologic conditions in ungaged watersheds and will provide a tool for month-to-month volume forecasting.</p>			
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PREFACE

The intent of this project was to evaluate the use of ERTS imagery in conjunction with more conventional methods for monitoring the progression of snowmelt in the Chena River watershed, Alaska. The specific objectives were directed toward:

1. Evaluation of satellite data as a tool for operational prediction of snowmelt runoff.
2. Characterization of the natural break-up pattern of the Chena River watershed.
3. Establishment of the relationship of observed break-up rates to quasi-permanent physiographic features and transient environmental factors.

For the Chena Basin (area: 5,100 km²), snow distribution was determined from ERTS imagery. A VP-8 image analyzer with density-slicing capabilities and automatic planimetering mechanism was used to determine areas of snow cover. Cloud-free ERTS imagery was obtained during the break-up on April 12 and 30 and May 2; satellite coverage was also available for several overflights prior to break-up. Later in May, excessive cloudiness prevented the use of ERTS imagery. Two aircraft flights were carried out on May 11 and 20. This aerial photography was quite helpful because it was the only data available to ascertain snowmelt rates at higher elevations.

A key part of this study was the comparison of ERTS results with both spot measurements at snow courses and the results of a snowmelt model. Very good agreement for snow distribution was found between the ERTS imagery, snowmelt model, and snow courses measurements. It has been

demonstrated that ERTS imagery can be successfully used to monitor the snowmelt of relatively small watersheds. In addition, percent snow cover during the melt period was studied for different slope aspects at varying elevations.

The main limitations of the ERTS imagery for transient hydrologic processes is the interval between overflights and the processing time. ERTS imagery will be of only limited use in operational forecasting; the imagery will be of more use for month-to-month volume forecasting. The satellite results should prove very useful in preliminary assessment of hydrologic conditions in ungaged watersheds.

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I. INTRODUCTION

A. Purpose of Report

This report transmits the final results of NASA ERTS-1 Project No. 110-5. The report satisfies the completion requirements of the scientific aspects of the project. The management and final fiscal reports will be handled as a separate portion of the University of Alaska's overall contract with NASA.

The intent of the project was to evaluate the use of ERTS data in conjunction with more conventional methods for monitoring the progression of snow break-up in the Chena River watershed. Specific objectives were directed toward:

1. Evaluation of satellite data as a tool for operational prediction of snowmelt runoff.
2. The characterization of the natural break-up pattern of the Chena River watershed.
3. Establishment of the relationship of observed break-up rates to quasi-permanent physiographic features and transient environmental factors.

B. Scope

This report represents all of the work done in conjunction with the ERTS-1 project, No. 110-5. Material for the report has been extracted in part from the several bi-monthly and two semi-annual progress reports which have already been transmitted to NASA. In addition, material from one technical paper has been included. These reports are listed in the Appendix.

The report uses a snowmelt model which has been developed under other sources of funding. The model is based on calculations from energy fluxes

at the surface of the snowpack. Cloudiness is used to estimate the rate of fluxes; temperature and windspeed are used to estimate the sensible heat flux and dew point; and windspeed is used to calculate latent heat flux. The final result is a comparison of ground truth data (snow depth and density), predictions of the snowmelt model, and results from the ERTS imagery.

C. Summary of Work Performed

Cloud-free ERTS imagery was obtained during the break-up on April 12 and 30 and May 2, 1973. Later in May, excessive cloudiness prevented using the ERTS imagery. Two aerial flights were carried out at a height of approximately 12,000 feet on May 11 and 20. A key part of the program was comparison of ERTS imagery with spot measurements of snow cover and the snowmelt model which had been developed by Carlson and Norton (1973). The results indicated that agreement was very good, especially when one considers the variability of the snowpack for point measurements. The percent of snow-free area over the basin was obtained from both the ERTS imagery and the aerial photography. These values were compared with that of the snowmelt model from which snowmelt runoff could be calculated from various altitude intervals by knowing the altitude, distribution and percent of area which is snow-free. An additional comparison was made between the snowmelt runoff of the model and that measured at several stream-gaging sites.

Results indicate that ERTS imagery can be successfully used to monitor the snowmelt of a relatively small watershed. Comparison with actual measurements and with the computer model showed good agreement. These same techniques can be used to study snowmelt behavior in watersheds of very little or no climatological or hydrological data. The information will make it possible to draw preliminary conclusions about

the most dynamic portion of the hydrologic cycle in the Arctic, the spring break-up.

II. DATA USED

Two forms of ERTS data were used to assess the rate of snowmelt break-up: 70 mm bulk black and white positive transparencies and 9-1/2 x 9-1/2 inch black and white bulk positive paper prints. Initially, the 70 mm transparencies were used with a color-additive viewer. MSS bands 6 and 7 were projected through colored filters for clear delineation of snow cover. There appeared to be little difference when using other band combinations to enhance snow cover.

Later, a VP-8 image analyzer (Interpretation Systems, Inc., Lawrence, Kansas) became available under project 110-1. This system has the following capabilities: single scan line display on a screen, digital readout of image intensities at any point, level slicing displayed as distinct colors, a pseudo three-dimensional display comprised of the x-y distance coordinates and intensity, and 5X magnification.

A built-in planimeter system allows aerial determination of distinct colors when performing level slicing. The VP-8 image analyzer proved to be an excellent tool for determining aerial extent of snow cover in the basin of interest. Previously, with the color-additive viewer, the areas of snow cover had to be planimetered by hand and the matching of images was very time-consuming. The VP-8 image analyzer helped decrease both the setup time and time consumed for determination of the area of coverage. MSS band 5 was used with the VP-8 image analyzer to plot snow cover and proved to be superior to other bands.

Imagery received from the ERTS satellite on 7 and 27 March, 12 and 30 April, and 2 May was used to map snow cover. Aircraft photography was planned during the two overflights of the satellite in May. The

aircraft photography was obtained on 11 and 20 May; no satellite images were received during this period because of cloudiness. However, the aircraft photography allowed continued monitoring of the rate of snowmelt in the Chena River Basin. A Bausch and Lomb zoom transfer scope was used to transfer contour lines from topographic maps to images from both the satellite and aircraft photography.

Several sources of ground truth data were utilized during this project. For the snowmelt model, climatological data (precipitation, wind, temperature, relative humidity and cloud cover) were obtained from the National Weather Service, U. S. Department of Commerce. Data on the depth and density of the snowpack was received for six points within the basin and three points immediately adjacent to the basin from the Soil Conservation Service, U.S. Department of Agriculture. Finally, continuous runoff data for two stations on the Chena River were received from the Geological Survey, Water Resources Division, U. S. Department of the Interior.

III. APPROACH OF INVESTIGATION

Of the many water resource problems faced by the State of Alaska, floods are the most widespread. The damage is large in small population centers and statewide, floods cause a great amount of damage annually. The art of prediction of flow is either on a day-to-day operational basis or as part of a long-term study has advanced to a rather high state of sophistication. There are available a number of computer-oriented, graphical, analytical, and empirical methods which are successfully used with experience. However, regardless of the degree of knowledge, the engineer or forecaster is limited by the completeness of the measured input. In the case of rainfall, the provision of adequate input data is quite straightforward. Snowmelt, on the other hand, provides an input

to the runoff system which, in itself, is the result of a rather complex process.

Snowmelt depends on a variety of factors, some of a permanent physiographic nature and others of a more transient environmental nature (Wendler, 1967). Because of the complexity of the process, snowmelt measurement on a point basis and extrapolation of point measurements even to a relatively small basin becomes very difficult. This is especially true of the Chena River in particular and Alaska in general. Hydrological and climatological networks are very sparse. For example, there are 25,000 stream-gaging stations in the United States as of 1970. Less than 1%, or 235 of these stations, are located in Alaska. By comparison, Alaska has 40% of the U.S. surface runoff from a drainage that is 1/6 the total area of the United States. These surface water stations have a density 1/20 that of the remaining 49 states. This sparseness of stations also is exhibited by the snow course network and the weather station network. As of 1970, there are only about 200 basic climatological stations recording only daily temperature extremes and precipitation. One-half of these stations make aviation-type observations which include cloud heights and amounts, visibility, wind, and pressure. Most of the climatological stations are located at lower elevations along the major rivers and their tributaries and along the coastline. As of 1970, there were only 101 snow courses in the State of Alaska. It should be noted that the northern 1/3 of the state, an area essentially north of the Brooks Range, lacks any snow courses. The distribution and number of various climatological and hydrological stations in Alaska are shown in Figures 1, 2 and 3.

Because of Alaska's severe cold climate, the surface hydrology for most of the state is only active during four to six months. As a result, the spring snow and ice break-up dominate the cycle and the resulting snowmelt runoff contributes most of the streamflow and causes many of the floods. For the Chena River Basin (Figure 4) major floods have

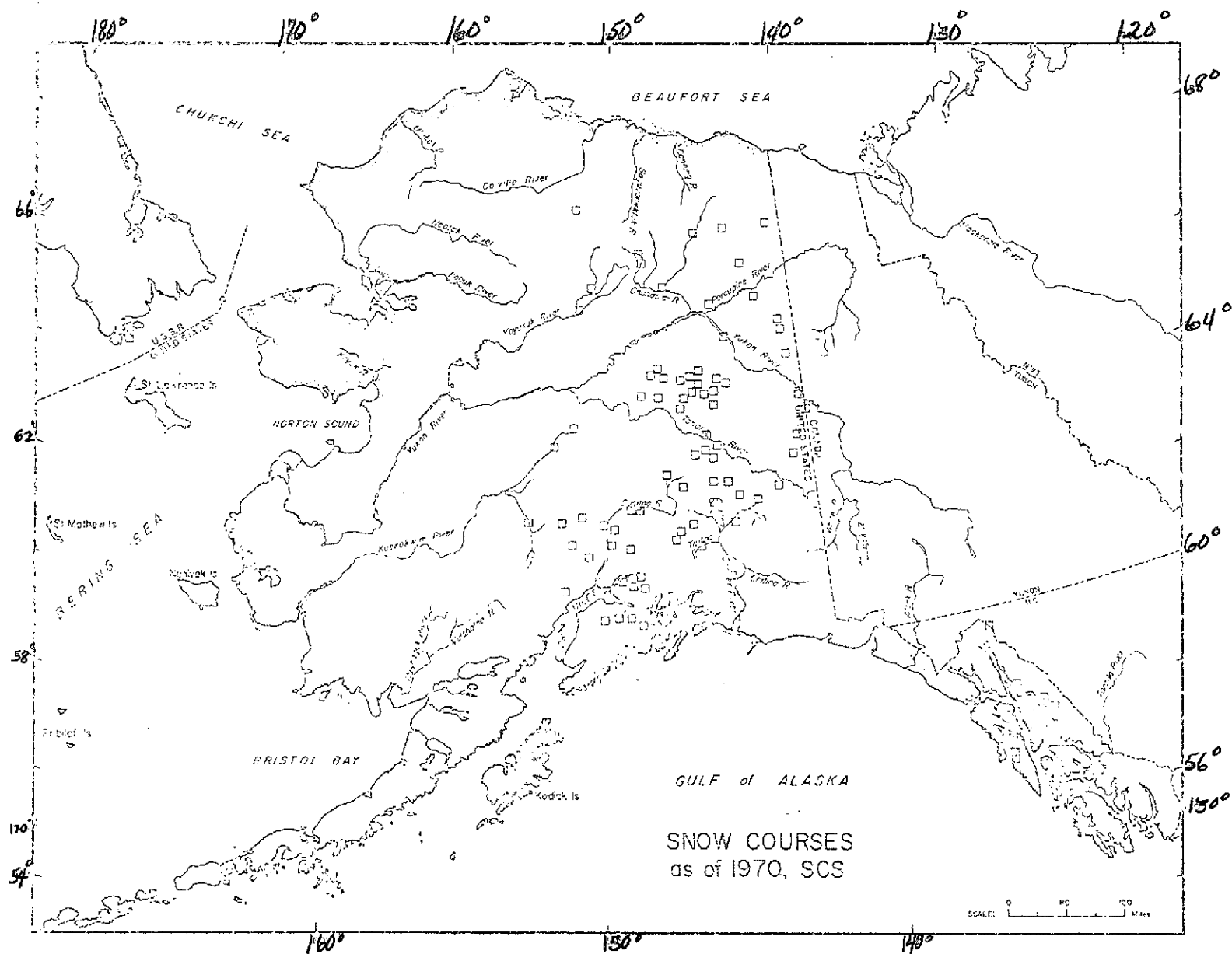


Fig. 1. Distribution of Snow Courses in Alaska

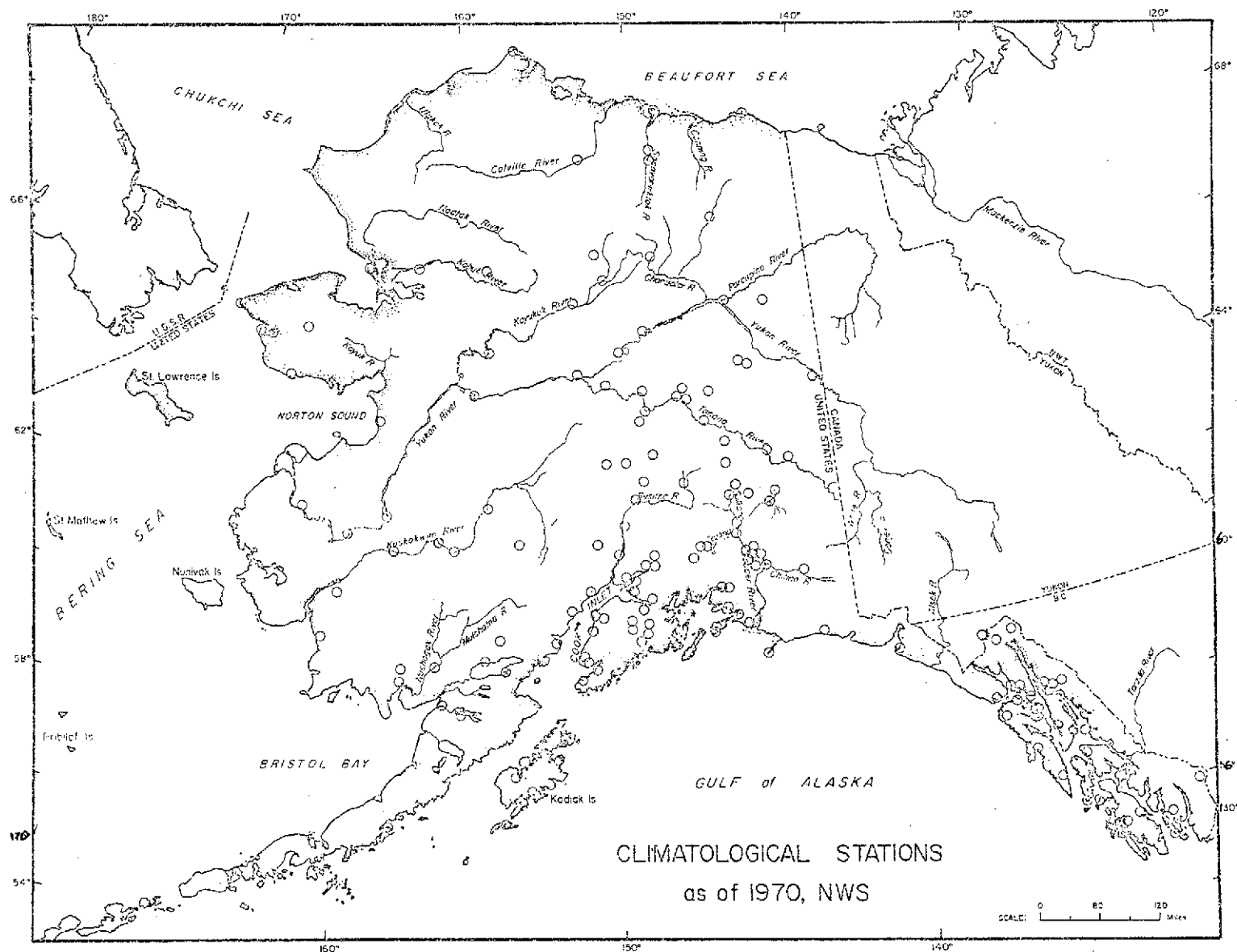


Fig. 2. Distribution of Climatological Stations in Alaska

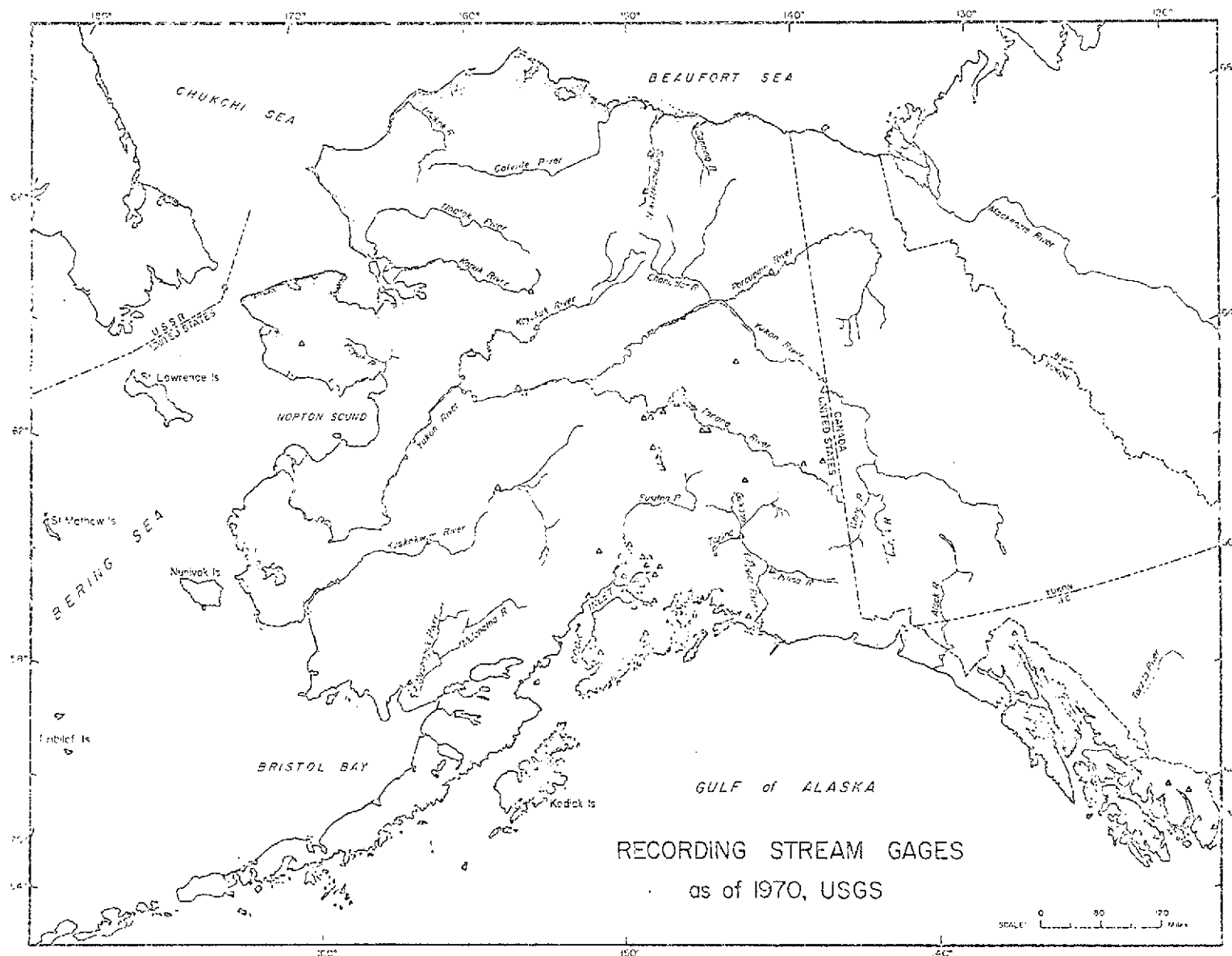


Fig. 3. Distribution of Recording Stream Gages in Alaska

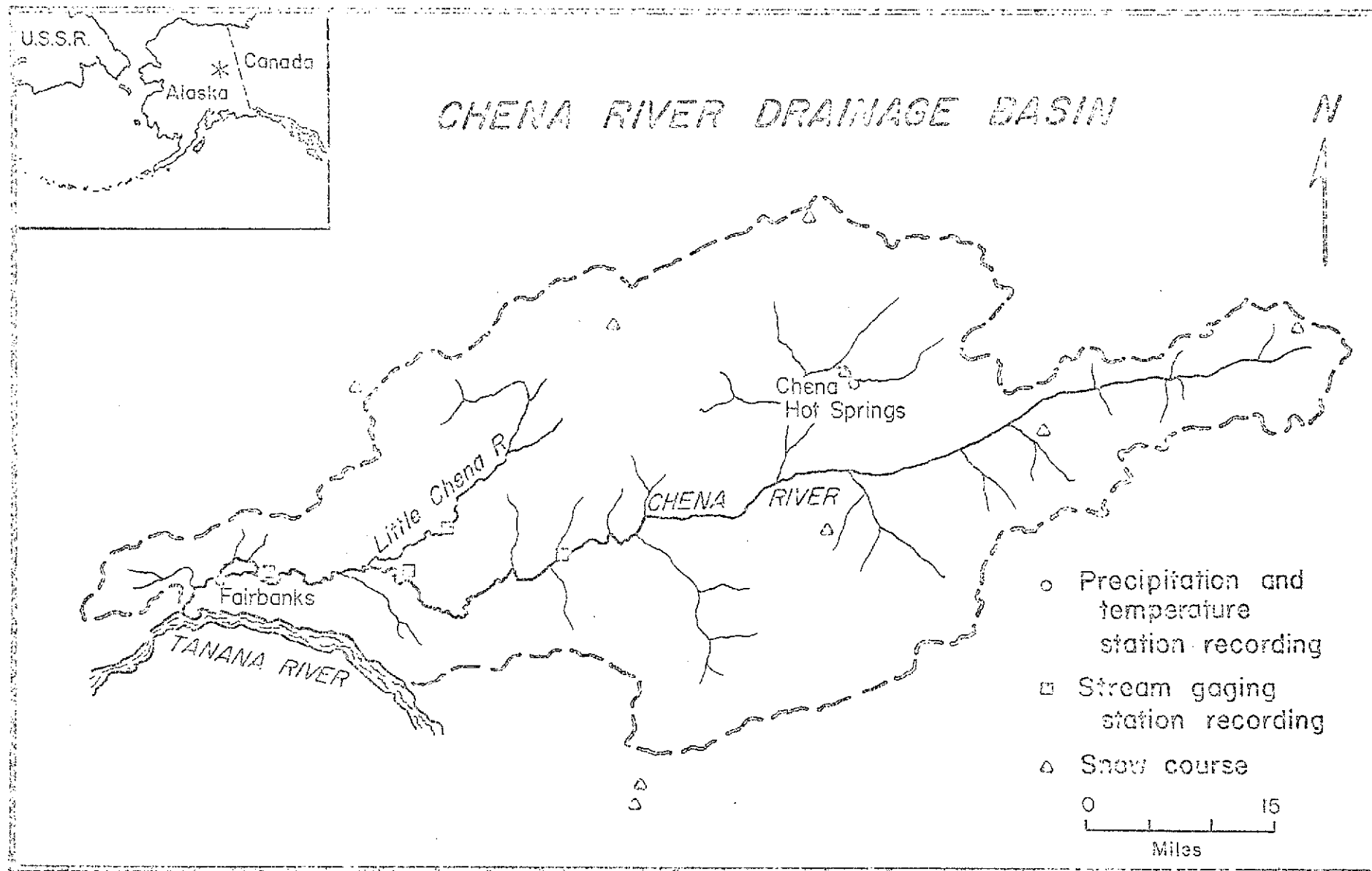


Fig. 4. Chena River Drainage Basin Map

occurred in the Fairbanks area in July, 1905; fall, 1906; May, 1911; spring, 1929; May, July, and September, 1930; May, 1933; May, August, 1934; April, 1936; May, 1937; August, September, 1945; May-June, 1948; and August, 1967. The average annual runoff of the Chena River at Fairbanks is 1,490 cfs, representing nearly 10 inches of runoff from a drainage area of 1,980 mi². The bankful channel capacity of the Chena River near Fairbanks is approximately 1,200 cfs. Minimum flows near 150 cfs and the maximum flow of 74,400 cfs have been recorded. The flow of 74,400 cfs occurred in August, 1967 from a maritime storm system. The next major flood in dimension occurred during the snowmelt period of 1948. Nearly 7.5 inches of runoff drained from the basin with a corresponding peak discharge of 24,200 cfs.

With the above problem in mind, this study concentrated on the use of ERTS data in conjunction with the more conventional methods to evaluate the progression of break-up in the Chena River watershed. The specific objectives of the project were to evaluate satellite data as a tool for operational prediction of snowmelt runoff, to characterize the natural break-up pattern of the Chena River watershed, and to relate the break-up rate to quasi-permanent physiographic features and transient environmental factors.

A complete description of the procedure used in this investigation is indicated in the remainder of the report. The following is a summation of the study plan. The extent of snow cover was determined by ERTS imagery of 12 and 30 April and 2 May 1973. No images were received for the remainder of the month of May because of cloudiness. To supplement the analysis, two aerial flights were carried out on 11 and 20 May over a portion of the basin. Since there was no satellite imagery available for the latter part of May, snow line elevations were taken from the aerial photographs. The percentage of the area covered by snow was then determined from area elevation curves (Figure 5).

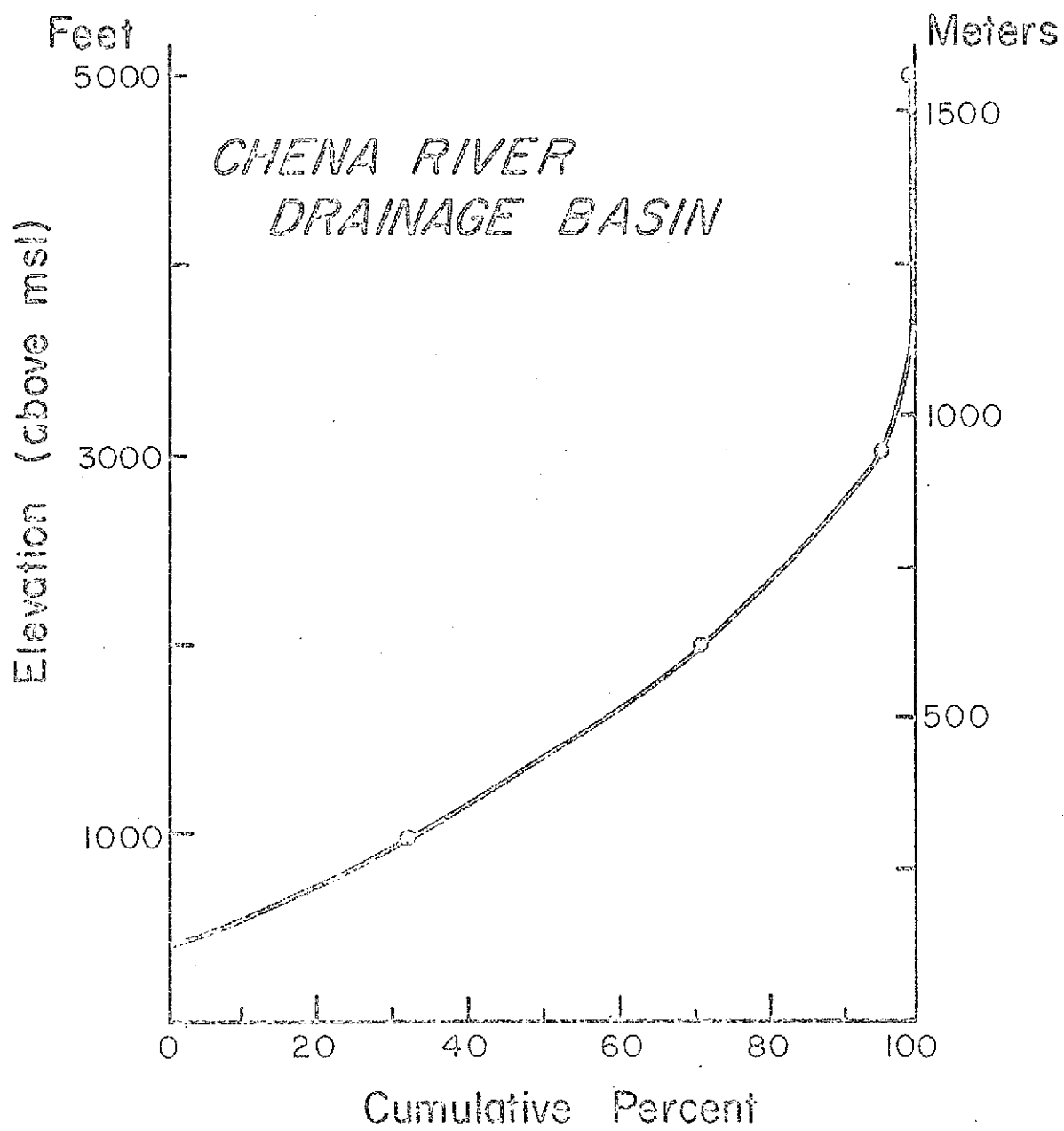


Fig. 5. Percent Area-Elevation Curve for Chena River Basin

The ground truth data obtained for comparison of satellite and aerial imagery was obtained primarily from the Soil Conservation Service, the National Weather Service and the U. S. Geological Survey. The Soil Conservation Service provided snow course information on request. The National Weather Service provided information on temperature, precipitation, wind, relative humidity and the degree of cloudiness (Figure 6). Streamflow data at two gaging locations was provided by the Geological Survey (Figure 7). Location of the ground truth observations are indicated on the drainage map of the Chena River.

As a supplement to the investigation, a snowmelt model which has been developed under another project was used. This model is based on a calculation of energy fluxes at the surface and within the snowpack. Cloudiness is used to estimate the radiative fluxes; temperature and wind speed are used to estimate the sensible heat flux; and dew point and wind speed are used to calculate the latent heat flux. Also, the process of melting at the surface and refreezing at deeper layers in the snowpack is considered. The flow chart for this model is shown in Figure 8.

The snowmelt model was used to determine the rate of ablation at four elevation intervals. The output portion of the model is daily incremental input to the watershed and snow depth (Figure 9). From the percent area-elevation curve and the incremental snowmelt input, the weighted snowmelt input for the entire basin can be calculated (Figure 10). It can be seen by comparing Figure 7 and Figure 10 that surface storage plays an important role in the snowmelt runoff process.

The results on snow depth from the computer model are compared on Figure 11 with actual snow course measurements. Percent of snow cover for the Chena River Basin can be determined from the computer output

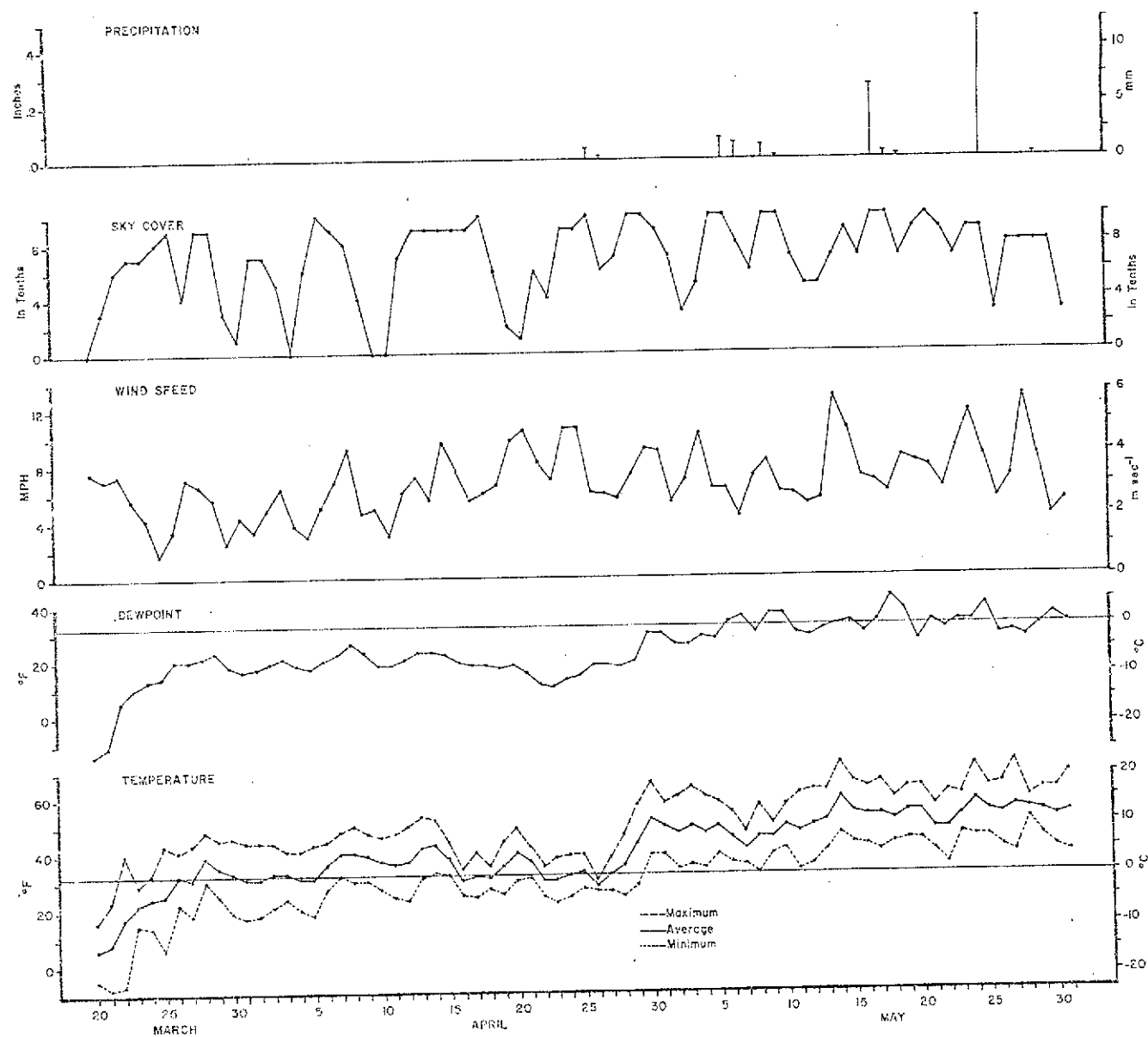


Fig. 6. Climatological Data During Snowmelt Break-Up, Fairbanks, 1973

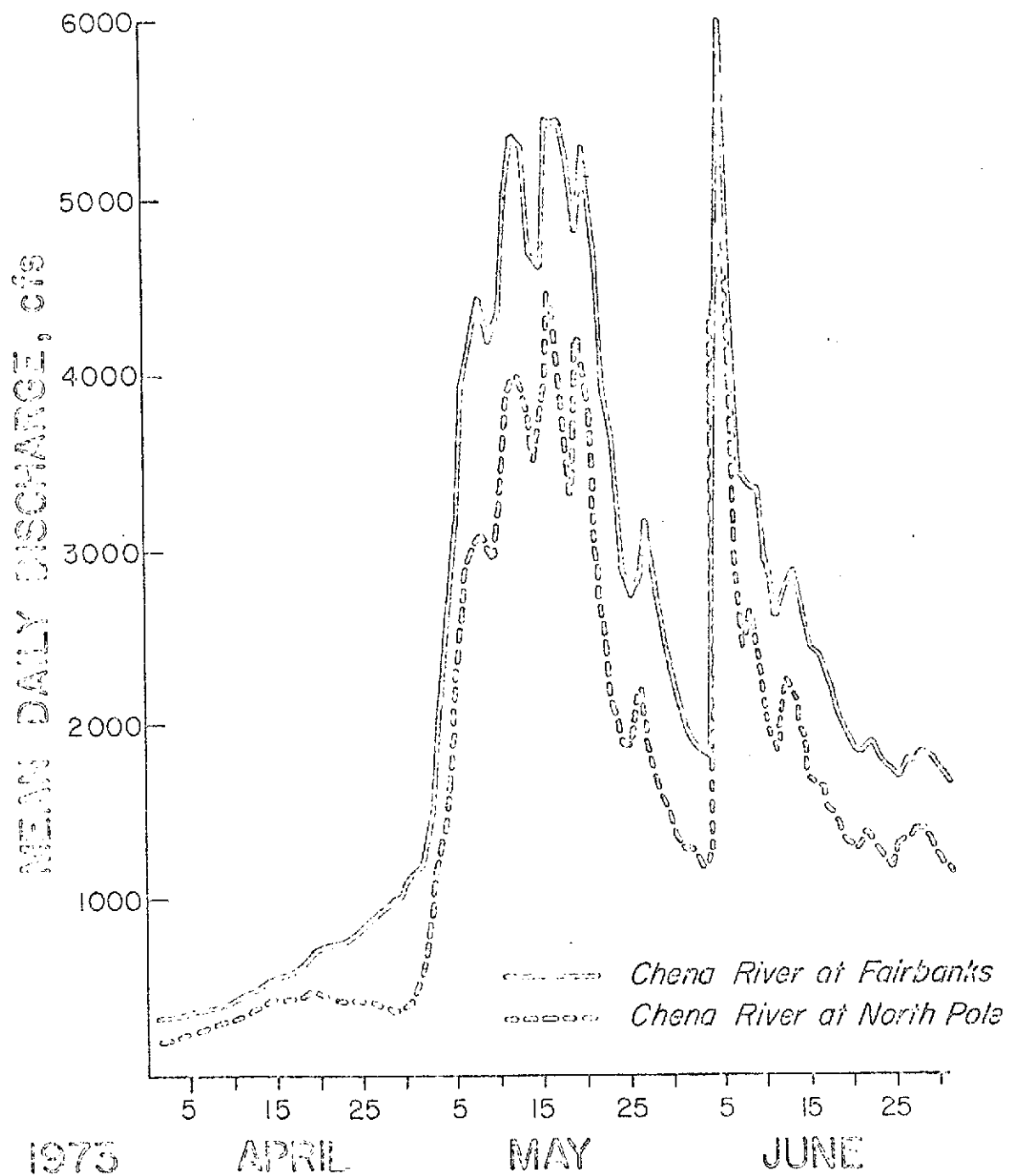


Fig. 7. Mean Daily Discharge During Spring Break-Up, Chena River

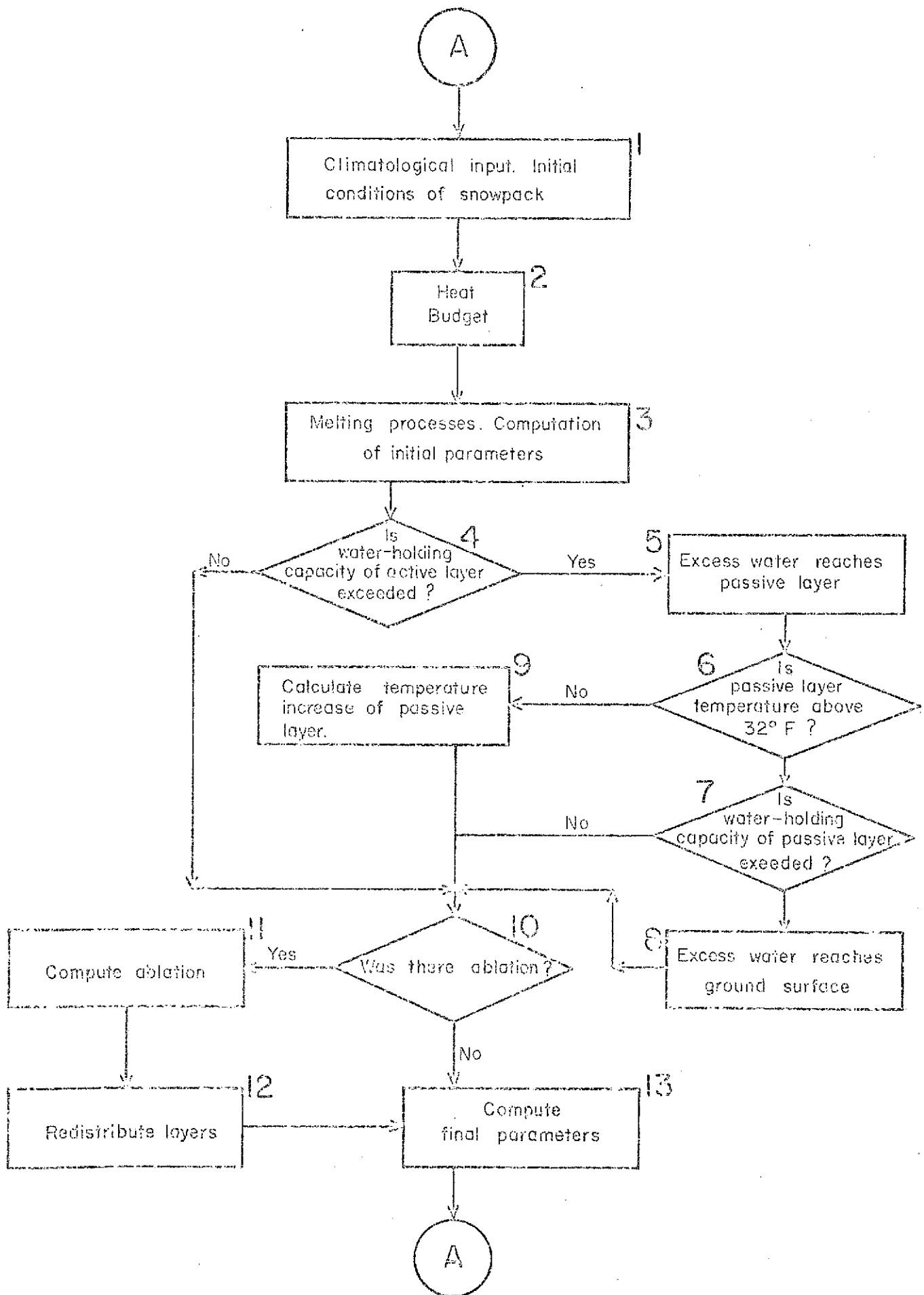


Fig. 8. Flow Chart for Computer Snowmelt Model

INCREMENTAL SNOWMELT INPUT TO WATERSHED, inches

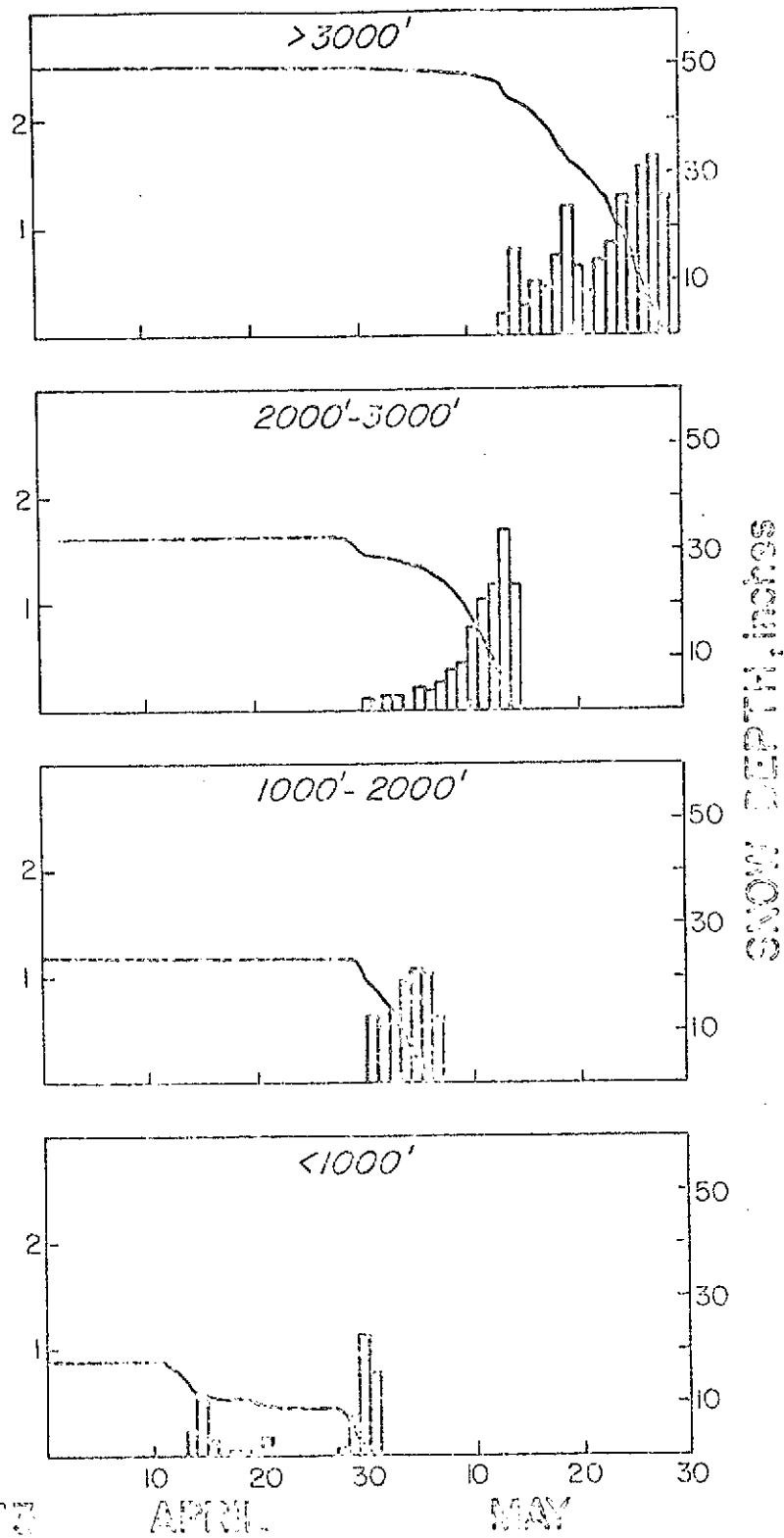


Fig. 2. Daily Incremental Snowmelt Input to Watershed From Snowmelt Model at Different Elevation Ranges

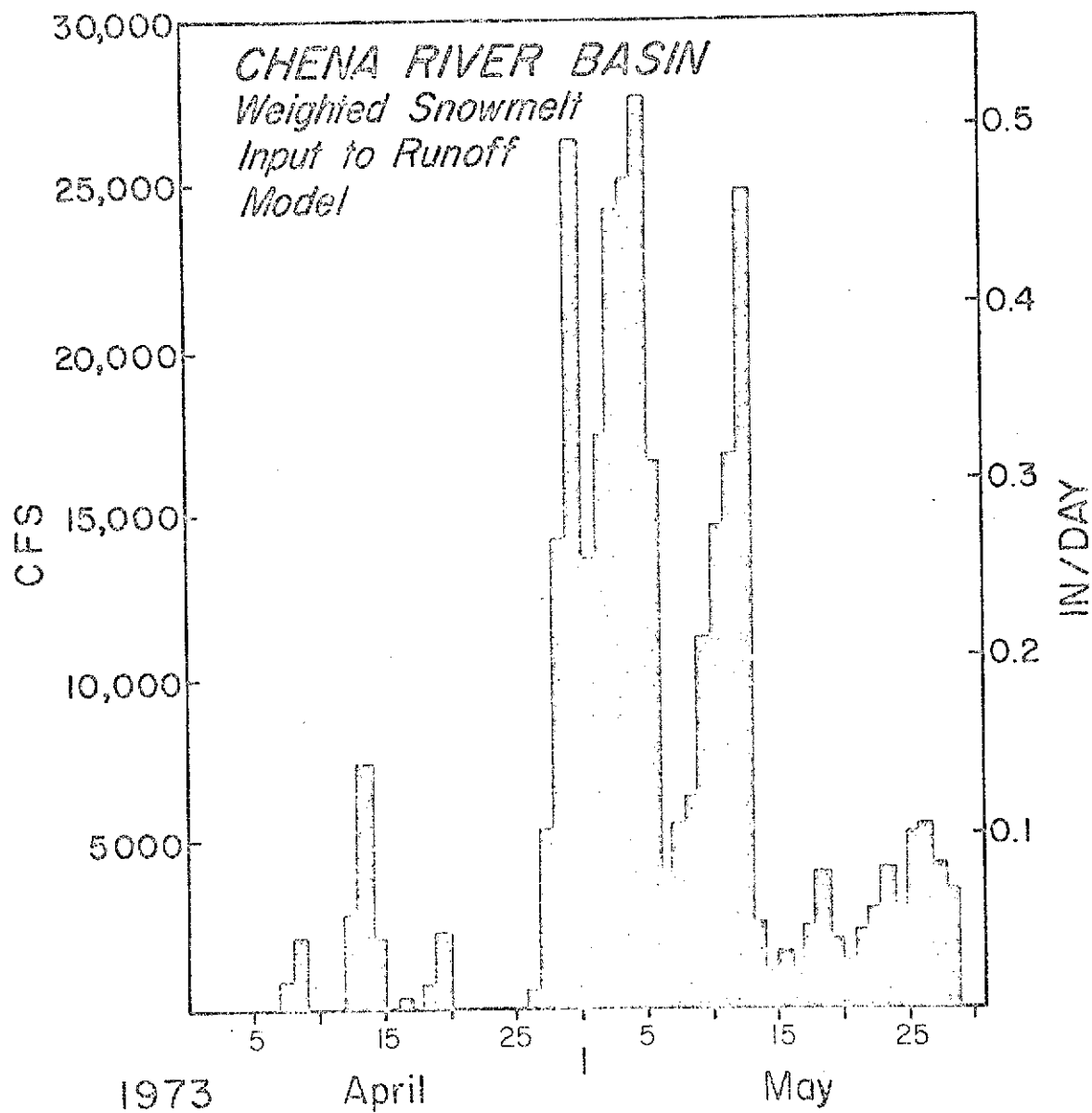


Fig. 10. Combined Snowmelt Input to Runoff From Snowmelt Model for the Entire Chena River Basin

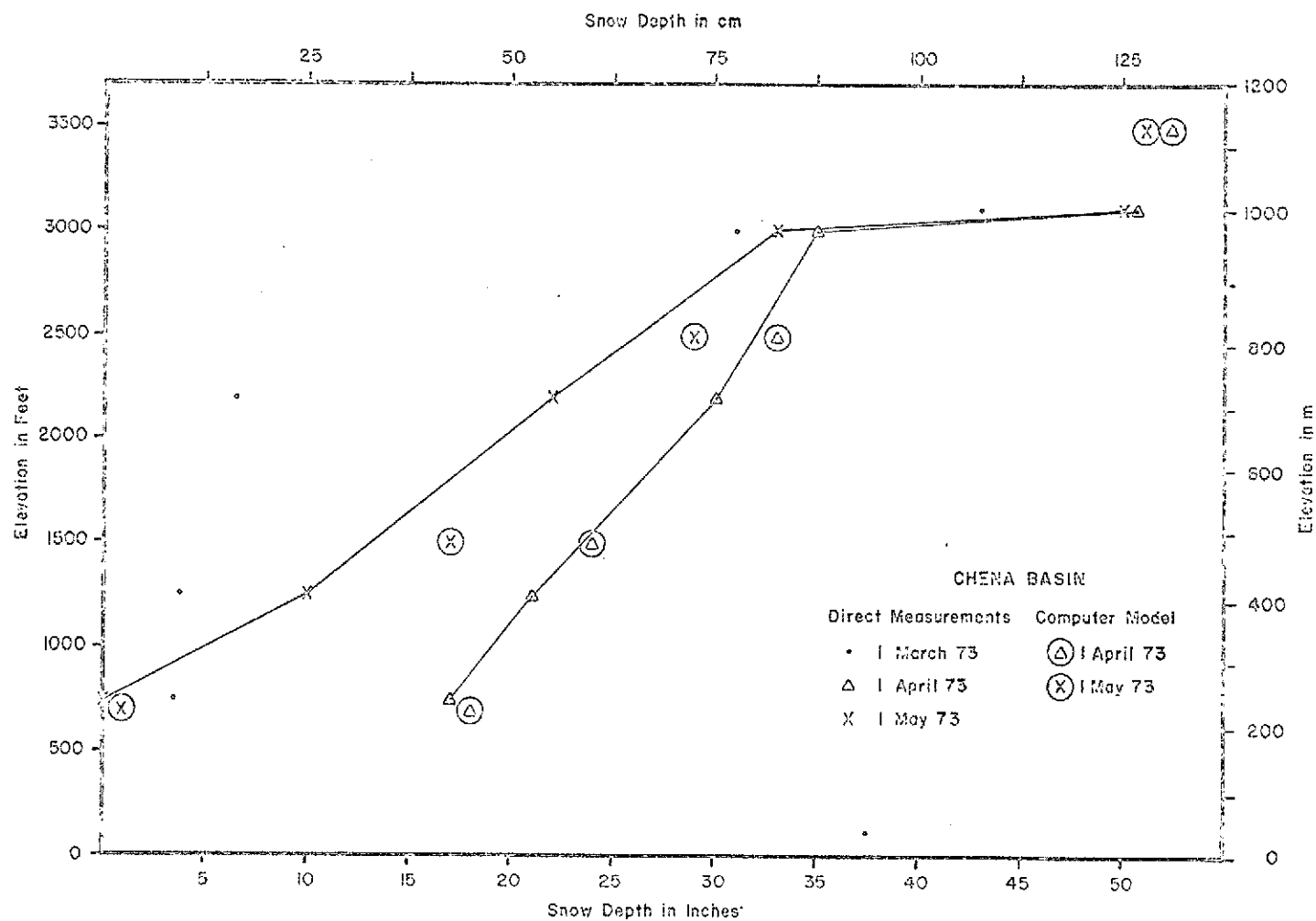


Fig. 11. Snow Depth vs. Elevation from Direct Measurements and Snowmelt Model

of the snowmelt model. These results are then compared with the percent of snow cover as determined from ERTS-1 imagery and aerial photography (Figure 12). The snowmelt model is tested against actual measurements for the spring of 1973 (Figure 13). The agreement is very good, especially if one considers the variability for point measurements of the snowpack.

The data obtained from this model might be compared, therefore, directly with the snow cover extent of the basin. The snowmelt runoff generated by the model was passed through a simple linear reservoir runoff model which simulated the effect of basin storage and channel delay. This predicted runoff was compared to the actual runoff as measured by the Geological Survey (Figure 7). A complete diagram of the interrelation between the various parts of the investigation is indicated on Figure 14.

IV. METHODS OF DATA ANALYSIS

Cloud-free ERTS imagery, both prior to the break-up on 7 and 27 March and during the break-up on 12 and 30 April, and 2 May 1973 were obtained. Two aerial flights at about 12,000 feet (3,660 meters) with stereo photography, were scheduled to coincide with the satellite passes during the month of May. The aerial flights were carried out on 11 and 20 May over part of the basin. Because of cloudiness, no satellite images were received for the latter part of May. Altitude lines were transferred from topographic maps onto the aerial photographs with a zoom transfer scope (Bausch and Lomb) and areas were obtained with a planimeter. For the ERTS imagery, utilization was made of the VP-8 image analyzer where false colors were assigned to the different levels of grey. This display allows one to eight intensity bands to be shown simultaneously.

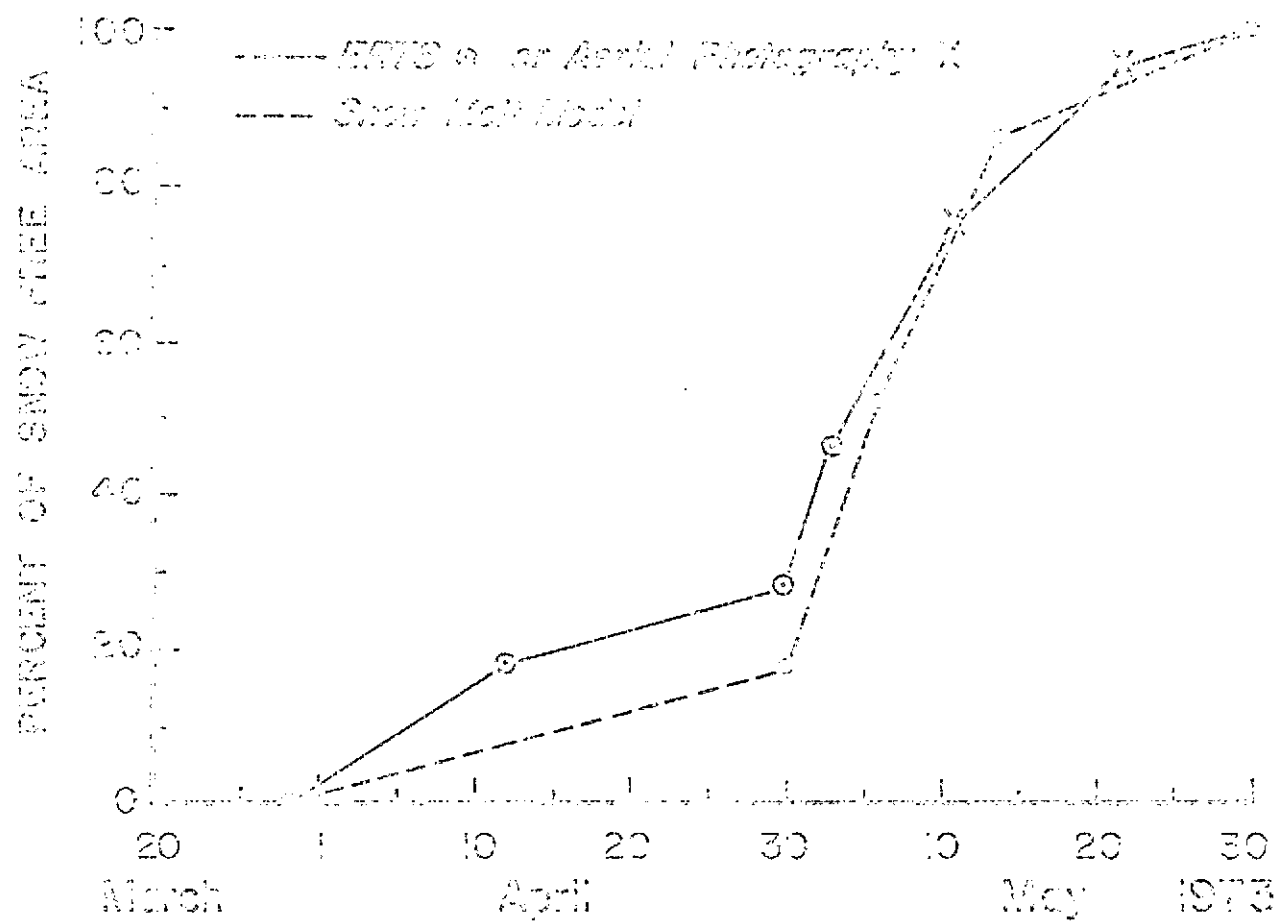


Fig. 12. Percent Snow Cover vs. Time from both the Snowmelt Model and ERTS Imagery

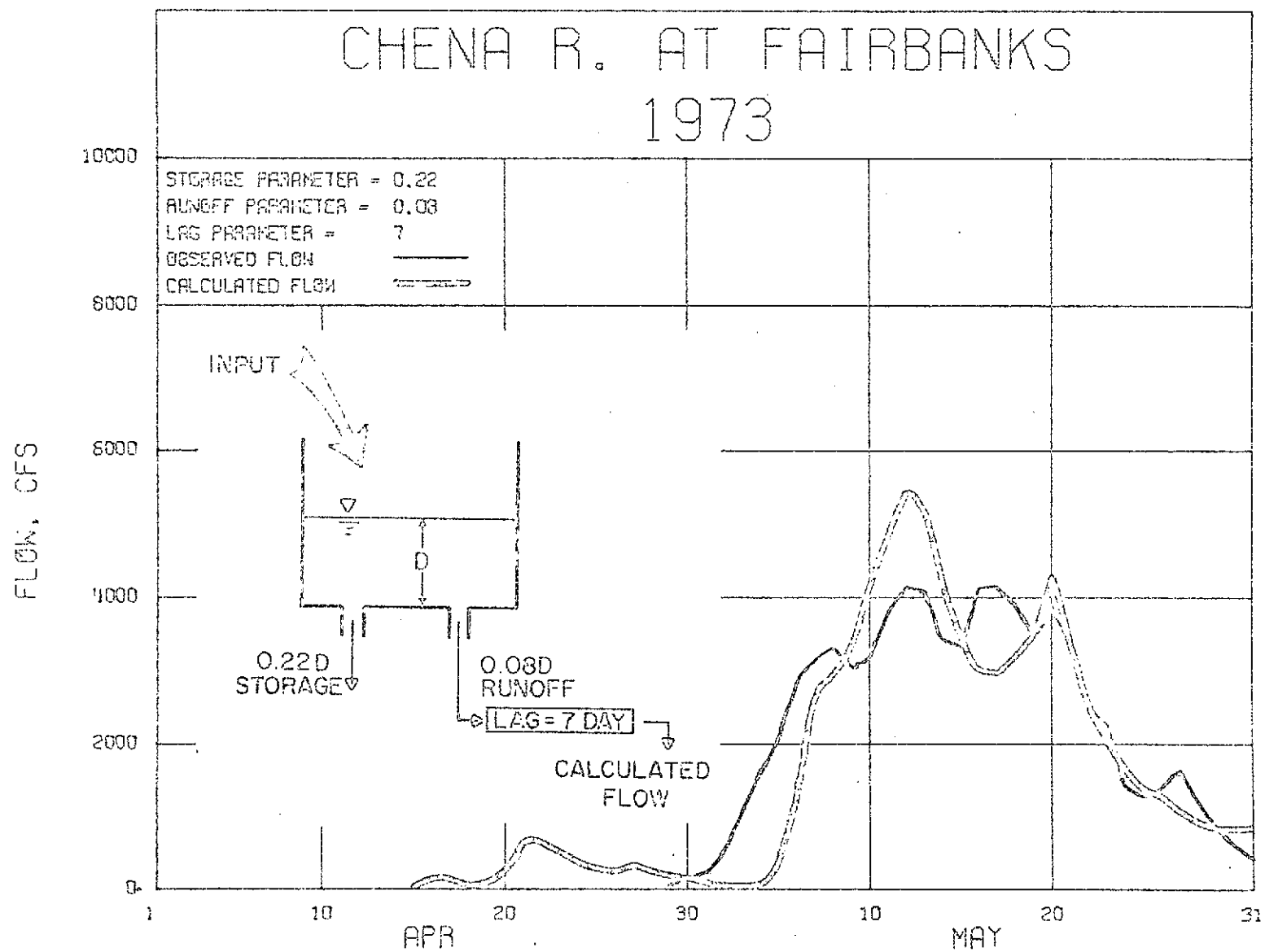


Fig. 13. Snowmelt Runoff vs. Time from Computer Snowmelt Model and Direct Measurements

CONVENTIONAL GROUND TRUTH

COMPUTER SNOWMELT MODEL

ERTS - 1 IMAGERY

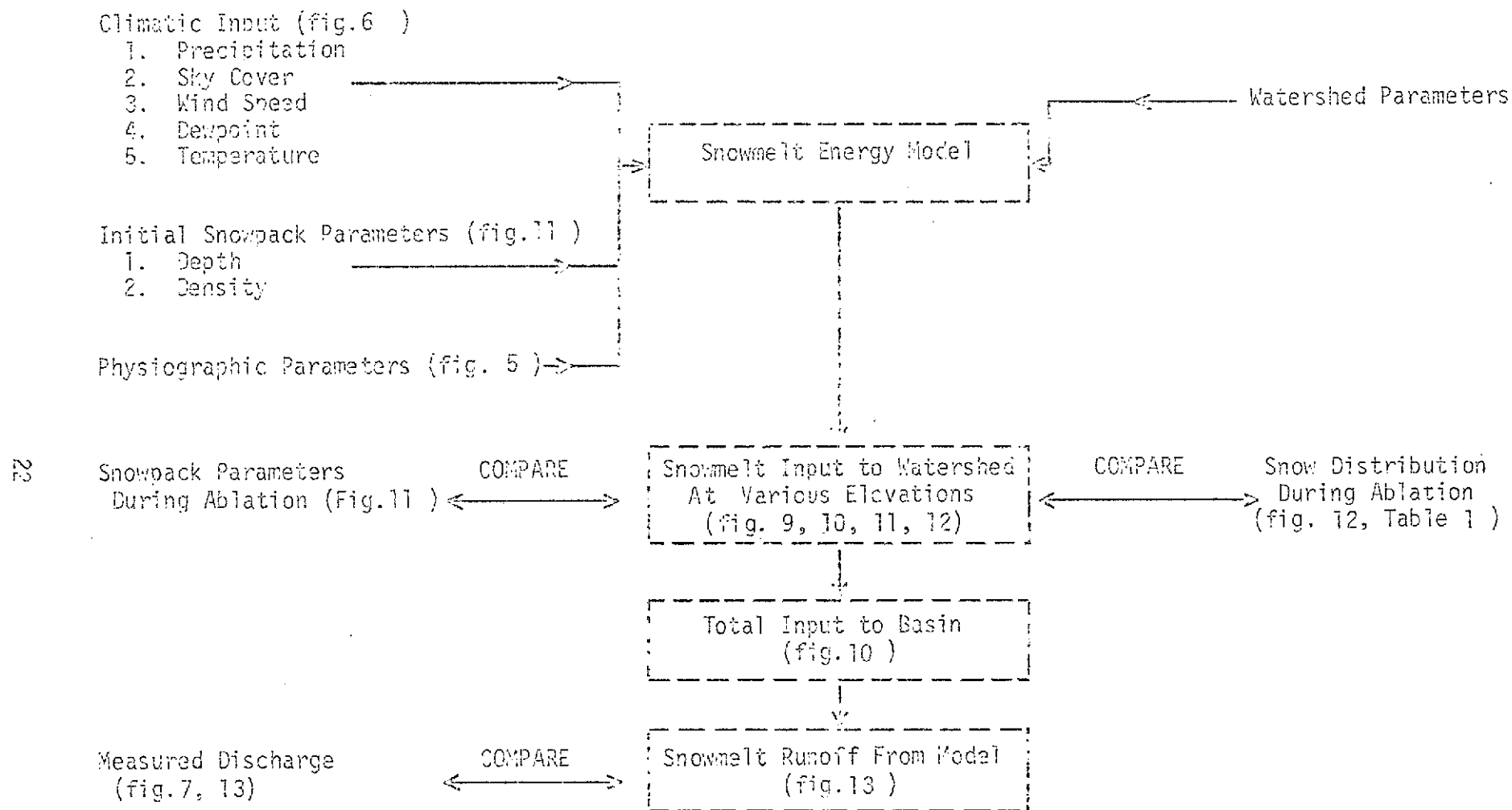


Fig. 14. Diagram Illustrating the Relationship Between the Ground Truth, Computer Snowmelt Model, and ERTS-1 Imagery.

Analysis of snow distribution with elevation and exposure revealed that patches of snow were found down to the lowest lying areas on north slopes on 11 May while no snow was found on a slope with a southerly exposure below 1,250 feet (380 meters) (Figure 15). The percentage of snow-covered area increased with altitude as illustrated by this figure. Therefore, areas having a similar percentage of snow cover for northerly and southerly exposures differed by 750 feet (230 meters) on 11 May and differed by 400 feet (120 meters) on 20 May. From 11 to 20 May, the lower limit of existing snow had changed in excess of 2,500 feet (780 meters). A decrease in snow cover for a northerly exposure on 11 May 1973 is accurate and depicts areas that are exposed to the wind above the existing tree line.

The Chena Basin was outlined on the cloud-free ERTS imagery for three dates during the ablation period during which pictures were obtained. Channel 5 (0.5 - 0.6 micrometers) was the best suited for distinguishing the snow cover from snow-free areas. An example is given in Figure 16 showing the Chena Basin on two occasions during break-up. The depletion of snow in the low-lying areas can be seen. The VP-8 image analyzer was used to obtain quantitative results. The various grey scales displayed in color were measured with an automatic built-in planimeter. Using this instrument, the following values were obtained:

TABLE 1
PERCENT OF SNOW COVER DETERMINED FROM
ERTS IMAGERY AND AERIAL PHOTOGRAPHY
CHENA RIVER BASIN (1,980 mi²)

Dates	Less than 50% Snow free or snow patches	Greater than 50% Broken or con- tinuous snow	
12 April 1973	18	82	5
30 April 1973	28	72	10
2 May 1973	46	54	15
11 May 1973	62	38	20
20 May 1973	98	02	25

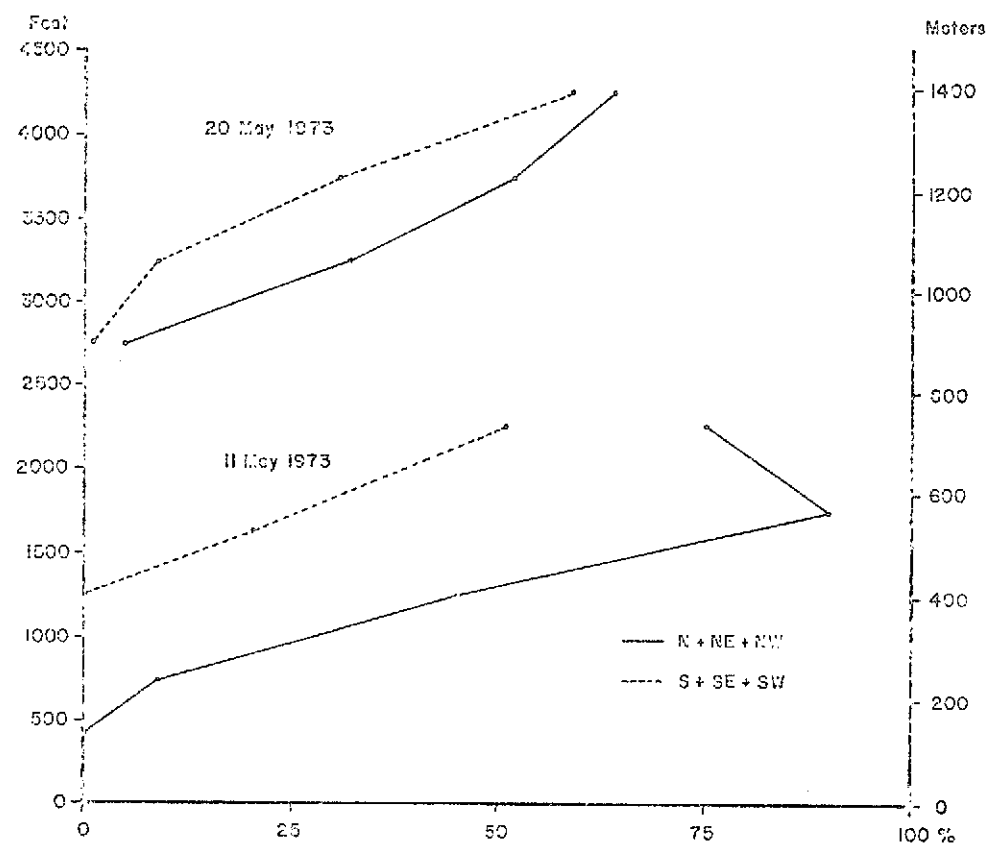


Fig. 15. Snow Cover as a Function of Elevation and Exposure

CHENA RIVER DRAINAGE BASIN

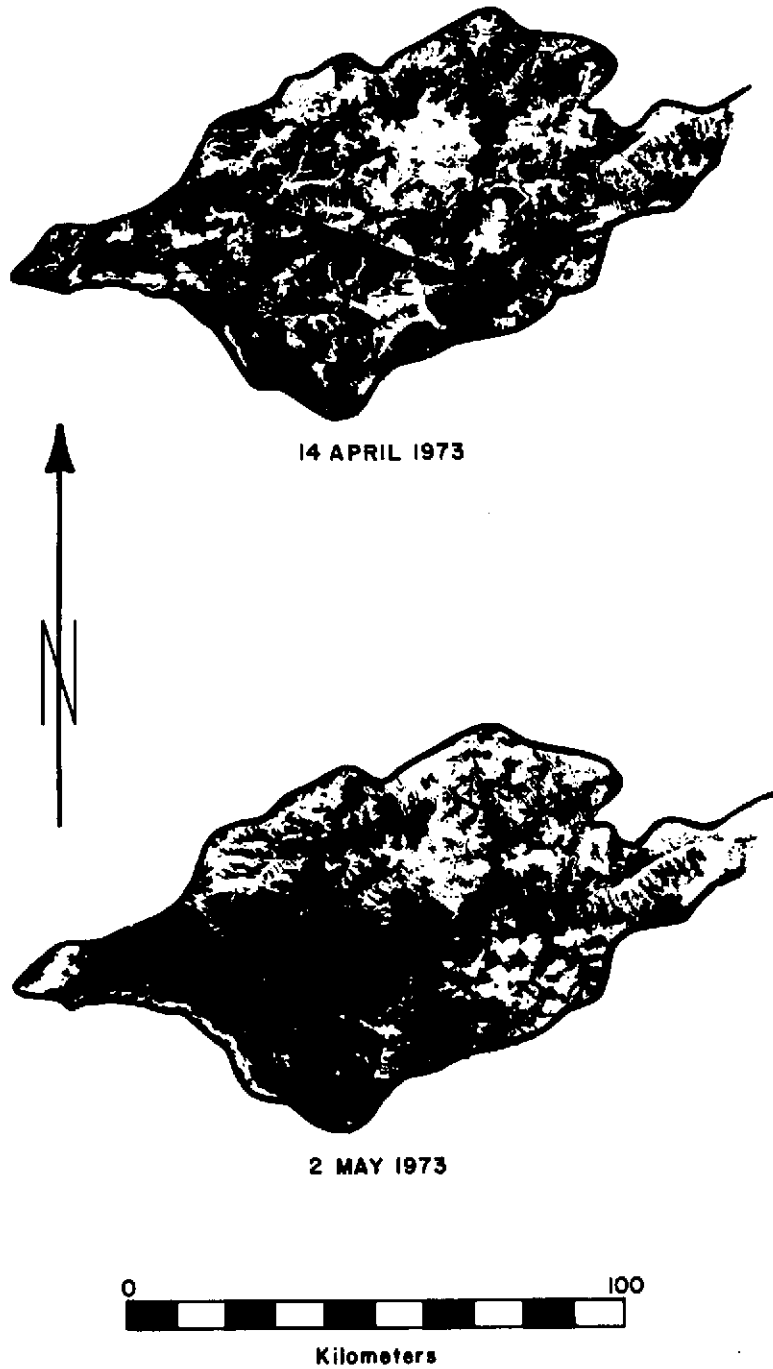


Fig. 16. ERTS-1 Imagery of the Chena River Basin

V. PRACTICAL APPLICATIONS

It appears that ERTS data will be most useful used in conjunction with snowmelt prediction models, existing snow course data, and aerial photography. Its great advantage, of course, is that it gives, in superb detail, a complete picture of a sizable river basin.

The main limitation is the lack of daily coverage. A picture once every 18 days simply is not often enough for a transient hydrologic phenomenon such as spring break-up.

In Alaska, because of the extremely sparse data network, any additional data would be quite useful. Now that ERTS imagery is available for the whole state, we expect that results of this and other projects will indicate the utility of the data in assessing the nature of the spring break-up occurrence on Alaskan watersheds to a wide variety of users. The ERTS-1 imagery will probably receive only limited use for operational forecasting. Its use will be limited by the 18-day coverage intervals and the difficulty in obtaining imagery in near real time. It is possible that the data will be more useful for the monthly volume-forecasting of the Soil Conservation Service as the time scale is not nearly as critical.

The most useful application of ERTS data for understanding spring break-up hydrology will be in ungaged areas. Alaska abounds with these areas and they are expected to become much more important with the extension of transportation routes throughout Alaska, both roads and oil and gas pipelines. We expect the ERTS imagery to become a standard useful tool for the professional hydrologist and to be quite useful when used in conjunction with other available means of estimating hydrologic occurrences.

VI. USE OF RESULTS

Throughout the project, we have maintained a close and informal contact with the two main interested parties for spring break-up data in Alaska, the Soil Conservation Service which issues monthly volume forecasts in the spring and the U. S. Weather Service Hydrologic Forecasting Office which issues daily flood stage forecasts during critical conditions. They have indicated high interest in the project and its results and have stated that they will quite likely incorporate ERTS imagery in a continuing program of understanding spring break-up phenomena of Arctic regions.

The interest of these two agencies plus the U. S. Geological Survey has been heightened somewhat by a recent plan for a real time telemetry network of hydrologic and climatologic data along the route of the TransAlaska pipeline. The agencies are currently cooperating in planning this system of some 53 stations, including 18 river crossing sites. All stations will be linked in real time to a central computer based in Anchorage. The agencies have submitted a request of \$2,800,000 to the Office of Management and Budget. As almost all of these sites will be established in what are now currently ungaged basins, extensive use of ERTS satellite imagery in assessing the nature of snowmelt break-up on these watersheds will result.

VII. NEW TECHNOLOGY

No new satellite evaluation technology was developed as a result of this project.

VIII. CONCLUSIONS

The results of this study have shown that ERTS imagery can be used to monitor snowmelt in relatively small watersheds. Comparison of ERTS imagery measurements with a computer model showed good agreement. These same techniques can therefore be used to study the snowmelt behavior in watersheds where little or no hydrological or climatological data has been collected. Such information will make it possible to draw preliminary conclusions about the most dynamic portion of the hydrologic cycle in arctic and subarctic watersheds.

The spatial distribution of the snowmelt break-up as monitored by ERTS imagery for the entire watershed is shown on Figure 12. Approximately 30 percent of the basin, primarily the low lying area (below 1000 feet msl), was snow-free prior to 30 April 73. The major runoff contribution from snowmelt occurred during the first 2 weeks of May as can be seen from the runoff hydrograph (Figure 7). There was an excellent comparison of percent snow-free area when determined from ERTS imagery and when determined from the snowmelt model. The input to the snowmelt model is primarily transient environmental data such as cloud cover, air temperature, wind speed, and dew point. ERTS imagery was also used to study snow cover as a function of physiographic features, mainly elevation and slope aspect. There is a significant difference in snow distribution (Figure 15) due to slope aspect. With differences of snow line exceeding 1500 feet in elevation.

ERTS imagery will be of only limited use in operational forecasting, that is, as additional data on a day-to-day forecast by an agency such as the National Weather Service. The ERTS imagery will be more useful for volume forecasting on a month-to-month basis as is done by the Soil Conservation Service.

We expect the ERTS imagery to find its greatest utility as an invaluable tool in assessing the nature of spring break-up process in Alaskan watersheds. This use will be particularly important in areas which are completely ungaged and when used in conjunction with a theoretical model of the watershed process such as the snowmelt and runoff models used in this study. Imagery will be useful in assessing the state of snow coverage disappearance in response to the meteorological parameters as direct input to the model, but also to expand the utility of what snow course events may be available in a given area. We expect the ERTS imagery to be particularly applicable to Alaska with the development of additional transportation routes, both roads and gas and oil pipelines. These routes will, for the most part, be extended through what are now completely ungaged watersheds and for which the snowmelt process is known in only an approximate manner.

ERTS imagery will have its greatest utility for these purposes when used in conjunction with other predictive and analytic techniques and field measurements.

IX. RECOMMENDATIONS

As pointed out in the previous sections of the report, the results of this study show that detection of the disappearance of snow during the spring break-up period is useful in understanding this important part of a subarctic watershed process. This study was done on a typical watershed in Interior Alaska. It was chosen both for its apparent representativeness and the relatively dense data network. The watershed is also conveniently located near the Fairbanks campus of the University of Alaska.

As a result of this study, we suggest that:

1. ERTS imagery should be examined for its usefulness in other areas of Alaska. Particular examination should be made of the utility of ERTS imagery in assessing the nature of spring break-up along transportation routes such as the TransAlaska pipeline.
2. Since the imagery would be much more useful if available more often than every 18 days, a possibility of a smaller time interval should be investigated. It does not appear to be particularly crucial to detection of snowmelt cover that the image should occur at the same time every day. Since, in Alaska, the main snowmelt break-up occurs within a month-and-a-half of the summer solstice, there would be nearly an eighteen hour period each day from which useful imagery could be obtained. This coverage at a smaller time interval could make the ERTS imagery tremendously useful for Alaska's hydrologic studies. This is especially true for snow cover detection as the breakup proceeds so fast in Alaska. It generally occurs over a period of 15 to 20 days and it is possible that in any given year, with the occurrence of one clouded image, that the important portions of the spring break-up could be missed entirely, using the current 18-days intervals of observation.
3. Images are now received 4 to 6 weeks after the satellite pass. For studying short-term processes such as snowmelt, this return time must be reduced greatly.

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